Final

pH (H^+ Ion Mass)

Total Maximum Daily Load (TMDL)

for

Wildcat Branch of Cumberland River Watershed (Pulaski County, Kentucky)

Kentucky Department for Environmental Protection

Division of Water

Frankfort, Kentucky

January 2006

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This report has been approved for release:

David W. Morgan

David W. Morgan, Director

Division of Water

1/13/06

Date

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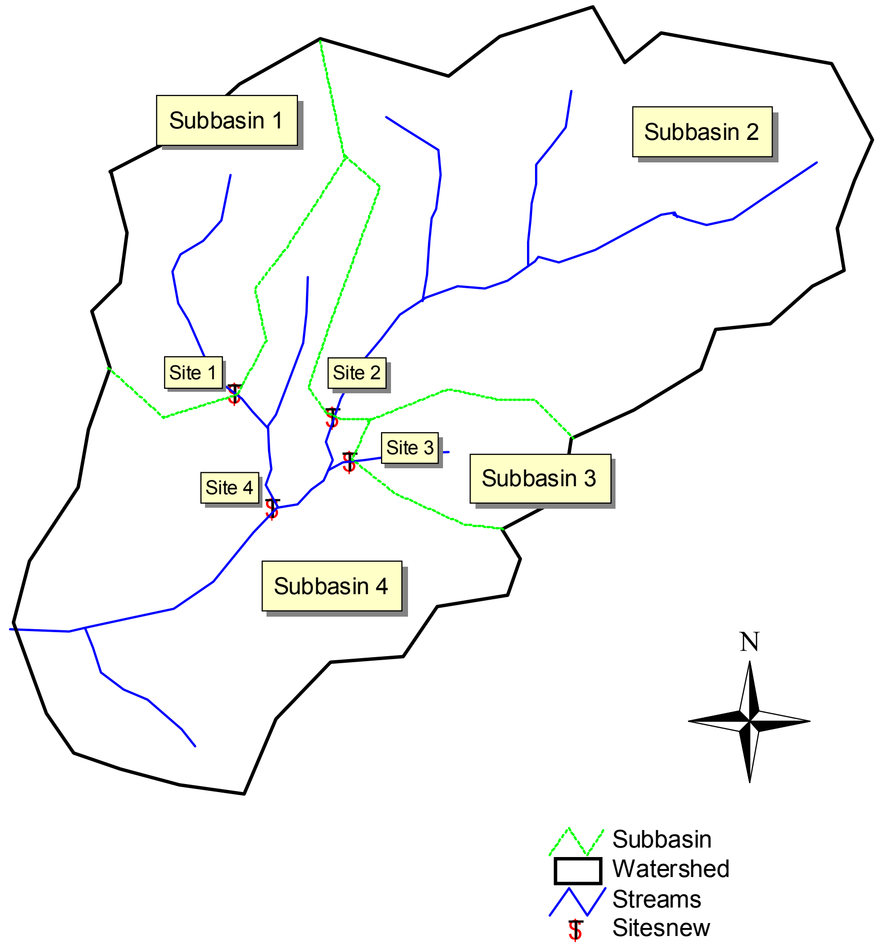
Wildcat Branch of Cumberland River

Total Maximum Daily Load (TMDL) Fact Sheet

Project Name:	Wildcat Branch of Cumberland River
Location:	Pulaski County, Kentucky
Scope/Size:	Wildcat Branch Watershed 1,234 acres (1.928 mi^2) Stream Segment: river mile 0.0 to 2.1
Land Type:	forest, agricultural, barren/spoil
Type of Activity:	acid mine drainage (AMD) caused by abandoned mines
Pollutant(s):	H^+ ion mass, sulfuric acid
TMDL Issues:	nonpoint sources
Water Quality Standard/Target:	The pH shall not be less than six (6.0) or more than nine (9.0) and shall not fluctuate more than one and zero tenths (1.0) pH unit over a 24-hour period. This standard is found within regulation 401 KAR 5:031.
Data Sources:	Kentucky Pollutant Discharge Elimination System Permit Historical Sampling Data, Kentucky Division of Water (KDOW) Data Collection
Control Measures:	Kentucky nonpoint source TMDL implementation plan, Kentucky Watershed Framework
Summary:	Wildcat Branch was determined as not supporting the designated uses of primary and secondary contact recreation (swimming and wading) and warm water aquatic habitat (aquatic life). Therefore, the creek was placed on the 1996 and subsequent 303(d) lists for TMDL development. The creek segment is characterized by a depressed pH, the result of AMD from abandoned mining sites. In developing the TMDL for Wildcat Branch, pH readings and corresponding streamflow measurements were made at four different locations within the watershed (see accompanying figure). The most recent sampling indicates that the entire watershed has unacceptable pH levels.



Wildcat Branch Subbasins

TMDL Development: TMDLs in grams H^+ ions per day were computed based on the allowable minimum pH value (6.0) for streams to meet primary and secondary contact recreation and aquatic life uses. The TMDL was done for grams of ions (subsequently converted to lbs/day) because the units for pH do not allow for the computation of a quantitatively useful load or reduction amount.

In recognition of the inherent difficulties associated with imposition of a "no-exceedance" pH criteria on potentially intermittent streams, the KDOW has decided to use the lowest one year average discharge of the most recent 10-year flow record as the flow basis for setting the appropriate TMDL and associated loading reduction. Previous pH TMDLs have used a 3-year recurrence interval of the average flow as the critical flow. However, this flow resulted in a target discharge that frequently was significantly greater than any of the observed flows for the sites as collected over several years. Thus use of a 3-year flow would require an extrapolation of the observed ion vs. flow model, well beyond the upper limit of the observed data. The selection of the 10-year frequency was based on a consideration of water quality standards (WQSs) (i.e. 7Q10). However, since many of these streams have a 7Q10 of zero, a greater duration was needed. The consensus of the KDOW was to use the 1-year duration. The use of an average annual flow as the basis for determining the TMDL provides a more appropriate mechanism for determining (1) the total annual load, (2) the total annual reduction that would be derived from an annual summation of the daily TMDLs, and (3) the associated daily load reductions for the critical year using historical daily flows.

TMDL for Wildcat Branch:

In developing a TMDL for Wildcat Branch, there are two possible strategies. Either a cumulative TMDL may be obtained for the downstream extent of the impaired portion of the watershed, or separate TMDLs and associated load reductions may be developed for each individual subbasin. As a result of the availability of sampling data at multiple sampling points, individual TMDLs were developed for Subbasins 1, 2, 3, and 4. The low pH condition extends to Site 4, which is the upstream extent of Subbasin 4. The TMDLs and associated load reductions for Subbasins 1, 2, 3, and 4 are shown below.

Summary of Flow Rate and TMDL for Each Subbasin In the Wildcat Branch Watershed

Subbasin	Upstream contributing area (mi^2)	Incremental critical flow (cfs)	Incremental TMDL for a pH of 6.0 (lbs/day)	Predicted incremental load (lbs/day)	Load Reduction needed (lbs/day)
1	0.2705	0.3287	0.0018	0.6496	0.6478
2	0.8456	1.0277	0.0055	7.4787	7.4732
3	0.1131	0.1375	0.0007	2.8267	2.8260
4	0.6988	0.8493	0.0046	39.9741	39.9695
Total Watershed	1.928	2.3433	0.0126	50.9291	50.9165

Permitting in the Wildcat Branch Watershed: All of the streams in the watershed are considered to be impaired for low pH based on the available data.

New Permits: New permits (except for new remining permits) for discharges to streams in the Wildcat Branch Watershed could be allowed anywhere in Subbasins 1, 2, 3, and 4 contingent upon end-of-pipe pH permit limits in the range of 6.35 to 9.0 standard units. WQSs state that for meeting the designated uses of aquatic life and swimming, the pH value should not be less than 6.0, nor greater than 9.0. This range of 6.0 to 9.0 for pH is generally assigned as end-of-pipe effluent limits. However, because a stream impairment exists (low pH), new discharges should not cause or contribute to an existing impairment. Application of agricultural limestone on mine sites results in highly buffered water leaving the site. A buffered solution with nearly equal bicarbonate and carbonic acid components will have a pH of 6.35 (Carew, personal communication, 2004). Discharge of this buffered solution will use up free hydrogen ions in the receiving stream, thus it should not cause or contribute to an existing low pH impairment. New permits having an effluent limit pH of 6.35 to 9.0 will not be assigned a hydrogen ion load as part of a Waste Load Allocation (WLA).

Remining Permits: Remining permits may be approved on a case-by-case basis where streams are impaired because of low pH from abandoned mines. Permit approval is contingent on reclamation of the site after mining activities are completed. Existing water quality conditions must be maintained or improved during the course of remining. The permittee is required to monitor in-stream conditions during remining to make sure that current water quality conditions are maintained or improved. Reclamation of the site is the ultimate goal, but WQSs (pH of 6.0 to 9.0 standard units) may not necessarily be met in the interim if the Commonwealth issues a variance to the discharger. In instances where the Commonwealth issues a variance for a remining activity consistent with this regulation, hydrogen ion loads from this remining activity are allowed to exceed the waste load allocation (WLA). The variance allows an exception to the applicable WQS as well as the TMDL. Remining therefore constitutes a means whereby a previously disturbed and unreclaimed area can be reclaimed. The authority for remining is defined in Section 301(p) of the Federal Clean Water Act; Chapter 33, Section 1331(p) of the U.S. Code – Annotated (the Rahall Amendment to the Federal Clean Water Act); and the Kentucky Administrative Regulations (401 KAR 5:029 and 5:040).

The remediation of the remining site will result in a reduction of the nonpoint source ion load of the subbasin where the remining is done. When remining is completed, the remediation should result in a reduction in the load allocation. Follow-up, in-stream monitoring will need to be done at the subbasin outfall to determine the effect of reclamation activities following remining on the overall ion load coming from the subbasin. There are currently no active remining permits in the Wildcat Branch watershed.

General KPDES Permit for Coal Mine Discharges: This permit covers all new and existing discharges associated with coal mine runoff. This permit does not authorize discharges that (1) are subject to an existing individual KPDES permit or application, (2) are subject to a promulgated storm water effluent guidelines or standard, (3) the Director has determined to be or may reasonably be expected to be contributed to a violation of a water of a WQS or to the impairment of a 303(d) listed water, or (4) are into a surface water that has been classified as an Exceptional or Outstanding or National Resource Water. A signed copy of a Notice of Intent (NOI) form must be submitted to the Kentucky Division of Water (KPDES Branch) when the initial application is filed with the Division of Mine Permits. However, coverage under this general permit may be denied and submittal of an application for an individual KPDES permit may be required based on a review of the NOI and/or other information.

Antidegradation Policy: Kentucky's Antidegradation Policy was approved by EPA on April 12, 2005. For impaired waters, general permit coverage will not be allowed for one or more of the pollutants commonly associated with coal mining (i.e., sedimentation, solids, pH, metals, alkalinity of acidity). The individual permit process remains the same except new conditions may apply if a Total Maximum Daily Load (TMDL) has been developed and approved.

Distribution of Load: Because there were no point source discharges active during the 2000-2002 monitoring period, the existing hydrogen ion load for the watershed was defined entirely as a nonpoint source load. Because new permits (pH 6.35 to 9.0) should not cause or contribute to the existing impairment and remining permits would be exempt from the TMDL requirements, no load has been provided for the WLA category.

Wasteload and Load Allocation for Each Subbasin in the Wildcat Branch Watershed

	Incremental Critical Flow Rate (cfs)	TMDL for pH = 6.0 (lbs/day)	Wasteload Allocation* (lbs/day)	Load Allocation (lbs/day)
Subbasin 1	0.3287	0.0018	0.00	0.0018
Subbasin 2	1.0277	0.0055	0.00	0.0055
Subbasin 3	0.1375	0.0007	0.00	0.0007
Subbasin 4	0.8493	0.0046	0.00	0.0046

*pH limits for new discharges must be between 6.35 and 9.0

Implementation/ Remediation Strategy: Remediation of pH-impaired streams, as a result of current mining operations is the responsibility of the mine operator. The Kentucky Division of Field Services of the Kentucky Department of Surface Mining Reclamation and Enforcement (DSMRE) is responsible for enforcing the Surface Mining Control and Reclamation Act of 1977 (SMCRA). The Kentucky Division of Abandoned Mine Lands (DAML), also a part of DSMRE, is charged with performing reclamation to address the impacts from pre-law and bond forfeiture mine sites in accordance with priorities established in SMCRA. SMCRA sets environmental problems as third in priority in the list of Abandoned Mine Lands (AML) problem types.

The Mt. Victory area of Pulaski County, Kentucky, which lies within the Wildcat Branch watershed, has a long history of coal mining with operations dating back to the Civil War. In the mid 1950's through the 1980's, this area was extensively mined using strip, deep, and auger mining techniques. The mines were operated at various times by Stokes, Mt. Victory, and Wash Ridge coal companies. Many of these mines were abandoned before they were successfully reclaimed. There are only a few areas where reclamation continues by bonded mining companies. Wildcat Branch, which is a tributary to Lake Cumberland, drains the Mt. Victory area. More than 100 years after coal mining began in this watershed, Wildcat Branch is still a heavily impaired stream.

Three separate reclamation projects have been implemented in the Wildcat Branch watershed during the last 10 years. A brief summary of each project is provided in the following sections.

Project #1

This project area is located in Subbasin 3 of the Wildcat Branch watershed. In 1992, the Forest Service acquired land in the Wildcat Branch watershed with hopes of reclaiming the area and improving water quality. The Forest Service took a watershed approach to solving the water quality in this stream by designing staged projects that would solve problems in the entire watershed. Through a series of anoxic limestone trenches, shallow wetland cells, and revegetation of bare areas, the water quality has been significantly improved. Recent water samples indicate water pH of 6-7 and metal concentration to be within state standards or acceptable limits. The project was completed in 1995 and cost approximately $77,000.

Project #2

This project area is located in Subbasin 2 of the Wildcat Branch watershed. This project routes water from a very acidic seep and through a series of underground limestone trenches and a wetland that is filled with limestone. By not allowing the limestone to come into contact with oxygen, bicarbonate alkalinity is produced without precipitating metal oxides that often armor limestone. Once the limestone is armored it is no longer effective in reducing AMD.

The initial results of this restoration effort are promising. Before treatment, the water from the seep had a pH value below 4. After flowing through the limestone trench and wetland, the pH was raised to a value of approximately 5. Heavy metals are also being dropped out of solution in the treatment system. Even though the water still does not meet Kentucky WQSs, the improvements are significant. In future years the water will be routed through additional treatment systems.

Project #3

This project area is also located in Subbasin 2 of the Wildcat Branch watershed. This is the most recent of the remediation projects completed in this watershed. The project was completed with assistance from the Kentucky Office of Surface Mining, and consists of the construction of three (3) ponds (lagoons) to treat AMD drainage. The project, known as "Wildcat Branch Mine Reclamation Project #4", was completed in July 1999. The Office of Surface Mining and Reclamation contributed $100,000 for this project. The project consists of a source of clean water flowing into a middle pond diluting some of the acid water, which flows through a limestone field into the third pond. The third pond is seeded with aquatic vegetation to create an acid treatment wetland, which should improve the water quality prior to its release into Wildcat Branch.

Introduction

Section 303(d) of the Clean Water Act and the Environmental Protection Agency's (EPA's) Water Quality Planning and Management Regulations (40 CFR Part 130) require states to develop total maximum daily loads (TMDLs) for their water bodies that are not meeting designated uses under technology-based controls for pollution. The TMDL process establishes the allowable loadings of pollutants or other quantifiable parameters for a water body based on the relationship between pollution sources and in-stream water quality conditions. This method exists so that states can establish water-quality based controls to reduce pollution from both point and nonpoint sources and restore and maintain the quality of their water resources (EPA, 1991).

Location

The Wildcat Branch watershed is entirely contained within Pulaski County, in southeastern Kentucky (Figure 1).

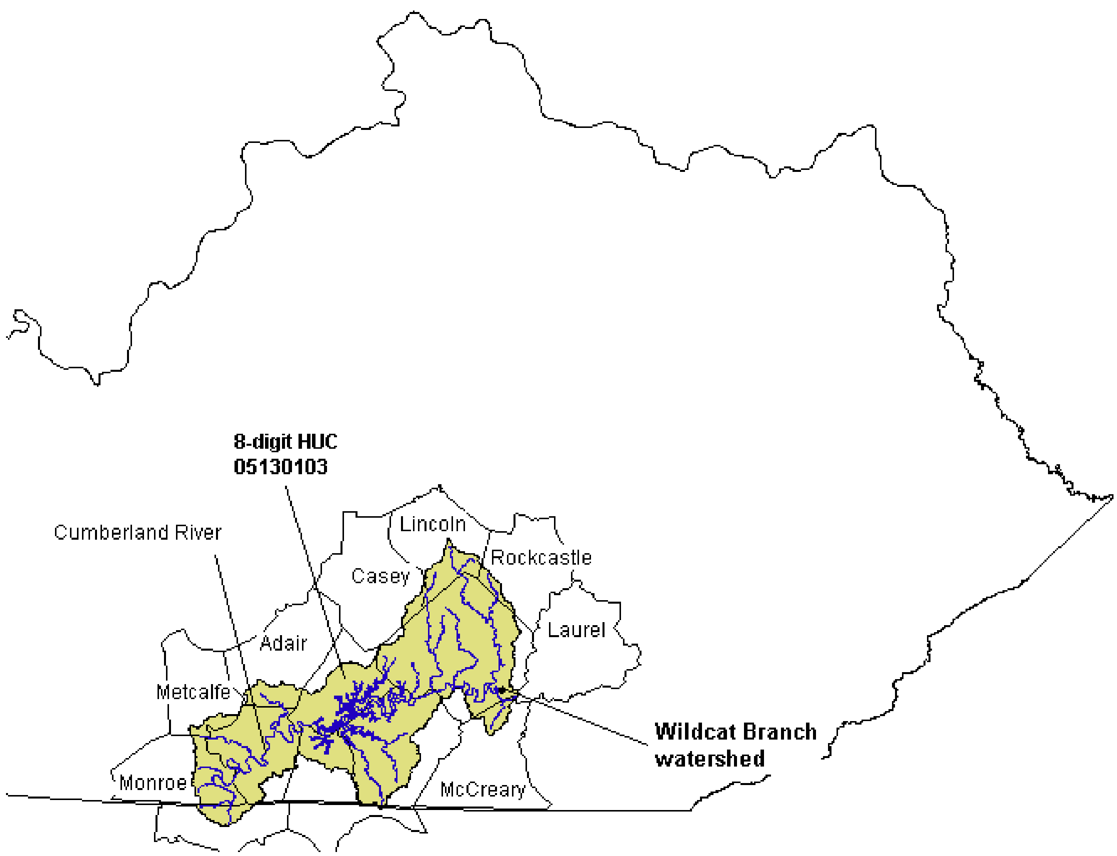


Figure 1. Location of the Wildcat Branch Watershed

Hydrologic Information

Wildcat Branch, a fifth order stream, originates in southern Pulaski County and flows southwest to discharge into the Cumberland River near River Mile 540. Wildcat Branch's mainstem is approximately 2.27 miles long and drains an area of 1,232 acres (1.93 mi^2). The average gradient is 0.025 feet per foot. Elevations for Wildcat Branch range from 1100 feet above mean sea level (msl) in the headwaters to 800 feet above msl at the most downstream point near its confluence with the Cumberland River.

Geologic Information

Wildcat Branch lies within the Eastern Coalfields region. This physiographic region is underlain by sandstone, siltstones, and shale of the Lee Formation of the Pennsylvanian System. Coal seams are found within the Lee Formation (US Department of Agriculture [USDA], 1974). The relief of the Wildcat Branch watershed ranges from sloping to moderately steep.

Landuse Information

Growing crops and raising livestock are the main enterprises in Pulaski County. Production of timber products also provides a major source of income and employment. About 210,000 acres of the county is woodland, about 24,000 acres of which are located in the Daniel Boone National Forest administered by the U.S. Forest Services.

Soils Information

Soils in Wildcat Branch watershed are dominated by sandstone and shale and are steep. Most of the soils are acidic and have a high content of clay in the subsoil.

Mining History

The Mt. Victory area of Pulaski County, Kentucky, which lies within the Wildcat Branch watershed, has a long history of coal mining with operations dating back to the Civil War. In the mid 1950's through the 1980's, this area was extensively mined using strip, deep, and auger mining techniques. The mines were operated at various times by Stokes, Mt. Victory, and Wash Ridge coal companies. Many of these mines were abandoned before they were successfully reclaimed. There are only a few areas where reclamation continues by bonded mining companies. Wildcat Branch, which is a tributary to Lake Cumberland, drains the Mt. Victory area. More than 100 years after coal mining began in this watershed, Wildcat Branch is still a heavily impaired stream.

The Wildcat Branch Mines site encompasses approximately 100 acres and includes four primary waste source areas associated with coal mining operations. The USDA Forest Service began purchasing land in these mine areas in the 1930s. The site is within the Cumberland River watershed, a waterway that is highly valued for its recreational usage and natural beauty. The Wildcat Branch Mines site has an approximate center point at N36º58'42.6", W84º25'05.2".

Mining permits in Kentucky are classified on the basis of whether the original permit was issued prior to May 3, 1978 (pre-law permit), after January 18, 1983 (post-Kentucky primacy) or between these dates (interim period). An explanation of the permit numbering system is provided in Appendix A.

Monitoring History

The waters of Wildcat Branch were monitored as early as 1978 by the Kentucky Division of Water (KDOW) as reported in *The Effects of Coal Mining Activities on the Water Quality of Streams in the Western and Eastern Coalfields of Kentucky,* published in 1981 by the KDOW as part of an agreement with the Kentucky Division of Abandoned Mine Lands (DAML). The U.S. Forest Service periodically collected data for pH and other constituents from 1993-99 at several locations within the watershed. Almost all of the data had pH observations below 6. This data prompted the 1996 303(d) listing of the entire stream as being impaired for swimming and wading and aquatic life uses because of low pH. Stream flow data was not collected as part of this effort.

Reclamation History

Three separate reclamation projects have been implemented in the Wildcat Branch watershed during the last 10 years. A brief summary of each project is provided in the following sections.

Project #1

This project area is located in Subbasin 3 of the Wildcat Branch watershed. In 1992, the Forest Service acquired land in the Wildcat Branch watershed with hopes of reclaiming the area and improving water quality. The Forest Service took a watershed approach to improving the water quality in this stream by designing staged projects that would solve problems in the entire watershed. Through a series of anoxic limestone trenches, shallow wetland cells, and revegetation of bare areas, the water quality has been significantly improved. Recent water samples indicate water pH of 6-7 and metal concentration to be within state standards or acceptable limits. The project was completed in 1995 and cost approximately $77,000.

Project #2

This project area is located in Subbasin 2 of the Wildcat Branch watershed. This project routes water from a very acidic seep through a series of underground limestone trenches and a wetland that is filled with limestone (see Figure 2). By not allowing the limestone to come into contact with oxygen, bicarbonate alkalinity is produced without precipitating metal oxides that often armor limestone. Once the limestone is armored it is no longer effective in reducing acid mine drainage (AMD).

Figure 2. Remediation Project #2: Wetland After Construction

The initial results of this restoration effort are promising. Before treatment, the water from the seep had a pH value below 4. After flowing through the limestone trench and wetland, the pH is raised to a value of approximately 5. Heavy metals are also being dropped out of solution in the treatment system. Even though the water still does not meet Kentucky water quality standards (WQS), the improvements are significant. In future years the water will be routed through additional treatment systems.

Project #3

This project area is also located in Subbasin 2 of the Wildcat Branch watershed. This is the most recent of the remediation projects completed in this watershed. The project was completed with assistance from the Kentucky Office of Surface Mining, and consists of the construction of three (3) ponds (lagoons) to treat AMD. The project, known as "Wildcat Branch Mine Reclamation Project #4", was completed in July 1999. The Office of Surface Mining and Reclamation contributed $100,000 for this project. The project consists of a source of clean water flowing into a middle pond diluting some of the acid water, which flows through a limestone field into the third pond. The third pond is seeded with aquatic vegetation to create an acid treatment wetland, which should improve the water quality prior to its release into Wildcat Branch.

The consensus among those involved with the restoration activities is that the problems are complex, full remediation will be costly and that actions at all the various sources and sites must be considered together in order to bring about a comprehensive solution.

Problem Definition

The 1996 and subsequent 303(d) lists of waters for Kentucky (KDOW, 1996, 1998, 2003) indicate that 2.1 miles of Wildcat Branch, from the upstream river mile point of 2.1 to the downstream river mile point of 0.0 in Pulaski County, do not meet the designated uses of primary (swimming and wading) and secondary (boating and fishing) contact recreation and warm water aquatic habitat (aquatic life). The Wildcat Branch watershed provides a classic example of impairment caused by AMD. Bituminous coal mine drainage, like that found in the Wildcat Branch watershed, generally contains very concentrated sulfuric acid and may contain high concentrations of metals, especially iron, manganese, and aluminum.

AMD can: (1) ruin domestic and industrial water supplies; (2) decimate aquatic life; and (3) cause waters to be unsuitable for swimming and wading. In addition to these problems, a depressed pH interferes with the natural stream self-purification processes. At low pH levels, the iron associated with AMD is soluble. However, in downstream reaches where the pH begins to improve, most of the ferric sulfate [$Fe_2(SO_4)_3$] is hydrolyzed to essentially insoluble iron hydroxide [$Fe(OH)_3$]. The stream bottom can become covered with a sterile orange or yellow-brown iron hydroxide deposit that impacts benthic algae, invertebrates, and fish.

The sulfuric acid in AMD is formed by the oxidation of sulfur contained in the coal and the rock or clay found above and below the coal seams. Most of the sulfur in the unexposed coal is found in a pyritic form as iron pyrite and marcasite (both having the chemical composition FeS_2).

In the process of mining, the iron sulfide (FeS_2) is uncovered and exposed to the oxidizing action of oxygen in the air (O_2), water, and sulfur-oxidizing bacteria. The end products of the reaction are as follows:

$$4\ FeS_2 + 14\ O_2 + 4\ H_20 + \text{bacteria} \rightarrow 4\ Fe + SO_4 + 4\ H_2SO_4 \qquad (1)$$

The subsequent oxidation of ferrous iron and acid solution to ferric iron is generally slow. The reaction may be represented as:

$$4\ FeSO_4 + O_2 + 2\ H_2SO_4 \rightarrow 2\ Fe_2(SO_4)_3 + 2\ H_2O \qquad (2)$$

As the ferric acid solution is further diluted and neutralized in a receiving stream and the pH rises, the ferric iron [Fe^{3+} or $Fe_2(SO_4)_3$] hydrolyzes and ferric hydroxide [$Fe(OH)_3$] may precipitate according to the reaction:

$$2\ Fe_2(SO_4)_3 + 12\ H_2O \rightarrow 4\ Fe(OH)_3 + 6\ H_2SO_4 \qquad (3)$$

The brownish yellow ferric hydroxide ($Fe(OH)_3$) may remain suspended in the stream even when it is no longer acidic. Although the brownish, yellow staining of the stream-banks and water does not cause the low pH, it does indicate that there has been production of sulfuric acid. The overall stoichiometric relationship is shown in equation (4):

$$4\ FeS_2 + 15\ O_2 + 14\ H_2O \longleftrightarrow 8\ H_2SO_4 + 4\ Fe(OH)_3 \qquad (4)$$

This reaction (eqn. 4) indicates that a net of 4 moles of H+ are liberated for each mole of pyrite (FeS_2) oxidized, making this one of the most acidic weathering reactions known.

Target Identification

The endpoint or goal of a pH TMDL is to achieve a pH concentration and associated hydrogen ion load in lbs/day that supports aquatic life and recreation uses. The pH criterion to protect these uses is in the range of 6.0 to 9.0 (Title 401, Kentucky Administrative Regulations, Chapter 5:031). For a watershed impacted by AMD, the focus will be on meeting the lower criterion. Water quality criteria have not been specified in terms of a particular frequency of occurrence. As pointed out in the recent NRC TMDL report (2001), "All chemical criteria should be defined in terms of magnitude, frequency, and duration. Each of these three components is pollutant-specific and may vary with season. The frequency component should be expressed in terms of a number of allowed flow excursions in a specified period (return period) and not in terms of the low flow or an absolute "never to be exceeded" limit. Water quality criteria may occasionally be exceeded because of the variability of natural systems and discharges from point and nonpoint sources." Small intermittent streams are especially vulnerable to this variability.

The Technical Support Document for Water Quality-Based Toxic Control (EPA, 1991b) states that daily receiving water concentrations can be ranked from the lowest to the highest without regard to time sequence. In the absence of continuous monitoring, such values can be obtained through continuous simulation or monte-carlo analysis. A probability plot can be constructed from these ranked values, and the frequency of occurrence of any 1-day concentration of interest can be determined. Where the frequency (or probability) of the resulting concentration is greater than the maximum exceedance frequency of the water quality target (e.g. once in 10 years), associated load reductions will be required until the resulting concentration is above the minimum target value (e.g. pH = 6.0). Where the load and the associated target value can be directly related through a flow rate (also referred to as discharge or streamflow), the frequency (or probability) of the associated flow rate (e.g. 365Q10) can be directly related to the frequency (or probability) of the target pH.

In recognition of the inherent difficulties associated with imposition of a "no-exceedance" pH criteria on potentially intermittent streams, the KDOW has decided to use the lowest one year average daily discharge of the most recent 10-year flow record as the flow basis for setting the appropriate TMDL and associated load reduction. Previous pH TMDLs have used a 3-year recurrence interval of the average flow as the critical flow. However, this flow resulted in a target discharge that frequently was significantly greater than any of the observed flows for the sites as collected over several years. Thus use of a 3-year flow would require an extrapolation of the observed ion vs. flow model, well beyond the upper limit of the observed data. The selection of the 10-year frequency was based on a consideration of WQSs (i.e. 7Q10). However, since many of these streams have a 7Q10 of zero, a greater duration was needed. The consensus of the KDOW was to use the 1-year duration. Use of an average daily flow over a one year period as the basis for determining the TMDL provides an appropriate mechanism for determining: (1) the total annual load; (2) the total annual reduction that would be derived from an annual summation of both the daily TMDLs; and (3) the associated daily load reductions for the critical year using the actual historical daily flows. The equivalent total annual load can be determined by simply multiplying the TMDL (derived by using the average daily flow) by 365 days. Likewise, the equivalent total annual load reduction can be obtained by multiplying the average daily load reduction (derived by using the average daily flow over a one year period) by 365 days. Although the 10-year average lowest daily flow (which roughly corresponds to the 365Q10) is typically only exceeded by approximately 20% of the days in the critical year, it still provides for explicit load reductions for approximately 80% of the total annual flow. For actual daily flows less than average flow, incremental load reductions may be accomplished by explicit imposition of a pH standard of 6 units.

Source Assessment

Point Source Loads

During the 2002 sampling period, there were no active permitted point source loads contributing to the existing pH impairment in the watershed.

Nonpoint Source Loads

In order to provide a more recent characterization of the pH levels in the watershed, personnel contracted by the UK Tracy Farmer Center for the Environment collected additional pH and streamflow values from the sites indicated in Table 1 and Figure 3. As can be seen from Table 1, all pH readings were below 6.0, indicating that the entire watershed is impaired because of low pH. The Tracy Farmer Center for the Environment used this data to develop the TMDL. A separate TMDL was developed for each subbasin as part of this study.

Table 1. Sampling Results for Wildcat Branch Watershed, 2002

	Site 1 – UT Lat 36°58'51" Long 84°25'41" RM 0.3 of 0.85		**Site 2** Lat 36°58'47" Long 84°25'26" RM 1.1		**Site 3 - UT** Lat 36°58'42" Long 84°25'23" RM 0.1 of 1.0		**Site 4** Lat 36°58'35" Long 84°25'3741" RM 0.80	
Date	Flow rate (cfs)	PH	Flow rate (cfs)	pH	Flow rate (cfs)	pH	Flow rate (cfs)	pH
2/18/2002	---	3.71	3.08	2.58	0.29	2.17	1.77	2.47
3/5/2002	---	4.4	0.76	3	0.08	2.5	1.31	2.9
3/12/2002	0.47	3.2	1.03	2.9	0.10	2.5	1.19	2.9
3/14/2002	0.21	4	0.73	2.8	---	2.4	1.27	2.7
3/19/2002	1.25	3.8	7.80	4	1.07	3.1	10.47	3.7
3/24/2002	1.35	4.2	6.06	3.4	0.51	2.8	3.58	3.2
3/27/2002	1.39	4.1	8.80	3.5	0.75	2.9	7.48	3.2
4/4/2002	0.87	4.1	4.79	3.4	0.54	3	4.01	3.3
4/25/2002	0.32	3.9	0.80	3.4	0.21	2.9	1.38	3.2
5/16/2002	---	3.75	---	2.85	---	2.57	---	2.76
5/23/2002	0.23	3.52	1.59	2.81	0.16	2.47	1.80	2.81

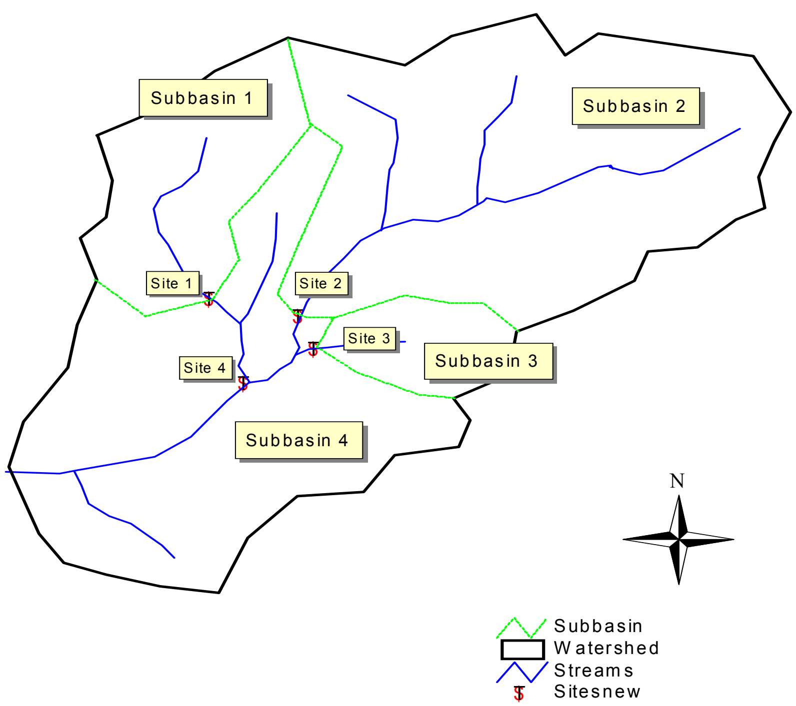


Figure 3. Recent Sampling Sites Monitored in the Wildcat Branch Watershed

TMDL Development

Theory

The TMDL is a term used to describe the maximum amount of a pollutant a stream can assimilate without violating WQSs, and it includes a MOS. The units of a load measurement are mass of pollutant per unit time (mg/hr, lbs/day). In the case of pH there is no direct associated mass unit (pH is measured in Standard Units).

The TMDL is comprised of the sum of individual wasteload allocations (WLAs) for point sources and load allocations (LAs) for both nonpoint sources and natural background levels for a given watershed. The sum of these components cannot result in exceedance of WQSs for that watershed. In addition, the TMDL must include a MOS, which is either implicit or explicit, that accounts for the uncertainty in the relation between pollutant loads and the quality of the receiving water body. Conceptually, this definition is denoted by the equation:

$$\text{TMDL} = \text{Sum (WLAs)} + \text{Sum (LAs)} + \text{MOS} \qquad (9)$$

Margin of Safety

The MOS is part of the TMDL development process (Section 303(d)(1)(C) of the Clean Water Act). There are two basic methods for incorporating the MOS (EPA, 1991):

1) Implicitly incorporate the MOS using conservative model assumptions to develop allocations, or

2) Explicitly specify a portion of the total TMDL as the MOS using the remainder for allocations.

Model Development

The magnitude of the associated hydrogen ion load in a water column (in terms of activity) can be determined by measuring the pH of the water. The relationship between hydrogen load and pH can be expressed as follows:

$$\{H_3O^+\} = 10^{-pH} \text{ or more commonly } \{H^+\} = 10^{-pH} \qquad (5)$$

Where pH is the negative log of the H^+ ion activity in mol/L. To convert between the measured activity $\{H^+\}$ and the actual molar concentration $[H^+]$, the activity is divided by an activity coefficient, γ.

$$[H^+] = \{H^+\}/\gamma \qquad (6)$$

The activity coefficient, γ, is dependent on the ionic strength μ of the source water under consideration. The ionic strength of a given source water can be approximated by estimating the TDS (total dissolved solids in mg/liter or ppm) and applying the following relationship (Snoeyink and Jenkins, 1980):

$$\mu = (2.5 * 10^{-5}) * TDS \qquad (7)$$

Alternatively, the ionic strength of a given source of water may be related to the measured specific conductance (SC) through the following relationship (Snoeyink and Jenkins, 1980):

$$\mu = (1.6 * 10^{-5}) * SC \qquad (8)$$

Ionic strength can be converted to an associated activity coefficient using the functional relationship shown in Figure 4 (Snoeyink and Jenkins, 1980).

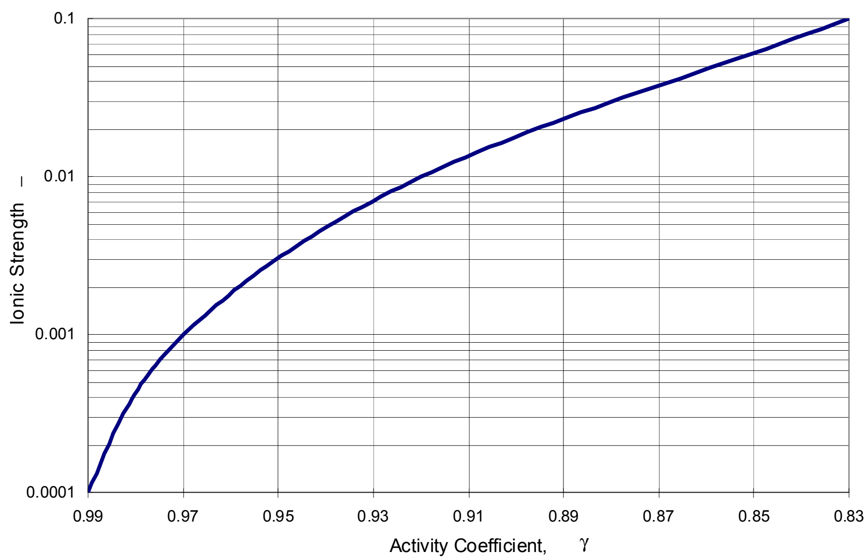


Figure 4. Activity Coefficients of H+ as a Function of Ionic Strength (Snoeyink and Jenkins, 1980)

In the absence of actual measured values of TDS or SC, an estimate of the upper limit of the ionic strength may be obtained from an evaluation of historic values of TDS or SC collected in the area. For example, an evaluation of over 141 measurements of SC obtained from streams in three eastern Kentucky counties (McCreary, Whitley, and Pulaski) has revealed a range of values from 2 to 3660 μ ohms/cm. Use of an upper limit of 3660 μ ohms/cm yields an ionic strength of 0.0586 or approximately 0.06. Use of a value of ionic strength of 0.06 yields an activity coefficient of approximately 0.85.

For the Wildcat Branch watershed, SC values were observed to vary from 2 to 2454 μ ohms/cm, which yield ionic strength values from 0.00003 to 0.03926 respectively. Application of Figure 4 for the observed ionic strengths in Wildcat Branch yields activity coefficients of 0.99 to approximately 0.87.

The atomic weight of hydrogen is one gram per mole. Thus, the concentration of hydrogen ions in mol/L is also the concentration in g/L. Multiplying the concentration of hydrogen ions by the average flow rate for a given day results in a hydrogen ion load for that day in g/day. As a result, for any given flow rate, there is a maximum ion load that the stream can assimilate before a minimum pH value of 6.0 is violated. Thus for any given day, a TMDL may be calculated for that day using the average daily flow and a minimum pH standard of 6 units.

Because pH and the equivalent hydrogen ion load can be related as a function of flow rate and ionic strength, a functional relationship can be developed between flow rate and the associated ion loading for a given pH value. By specifying a minimum pH value (6) and an associated minimum activity correction factor (0.87), an envelope of maximum hydrogen ion loads that could still yield a pH of 6 may be obtained as a function of flow rate (see the upper $TMDL_x$ curve in Figure 5). In using the proposed methodology, the MOS may be incorporated explicitly through the properties of water chemistry that determine the relationship between pH and hydrogen ion concentration. In an electrically neutral solution, the activity coefficient (γ in equation 6) is assumed to be equal to 1.0, meaning that there is no quantitative difference between activity and molar concentration. In the case of AMD there obviously exists the possibility of additional ions in the water column that may affect the relationship between the measured activity and the associated ion load. SC values in Wildcat Branch have been found to be in the range from 3 – 2040 μ ohms/cm, which yields ionic strength values of between 0.00003 and 0.03260 respectively. Application of Figure 4 for the observed ionic strengths in Wildcat Branch yields activity coefficients of 0.99–0.87. In developing a pH TMDL for Wildcat Branch, a conservative activity coefficient of 1.0 was assumed which provides for a MOS of approximately 13 percent in determining the associated TMDL. This is because the activity coefficient of 0.87 was used in calculating the actual load. Even though this MOS can be deemed as an explicit MOS, for this TMDL it will be expressed as an implicit MOS because a conservative assumption has been used in the model to determine the value of the TMDL. To develop a TMDL for an impaired stream, the most conservative approach would be to assume an activity coefficient of 1.0, which would yield the lowest value for the TMDL for a given range of activity coefficients (see lower $TMDL_1$ curve in Figure 5). The difference between the maximum $TMDL_x$ (based on the observed activity coefficient) and the minimum $TMDL_1$ (based on an activity coefficient of 1.0) would provide a margin of safety (MOS) in setting the TMDL for the stream as well as for calculating the associated load reduction. In developing a TMDL for the Wildcat Branch Watershed, the TMDL for each of the Subbasins 1, 2, 3, and 4 will be established assuming an activity coefficient of 1.0, while the observed load will be determined using an activity coefficient of 0.87, providing for an upper limit of a MOS of approximately 13 percent. Even though this MOS can be deemed as an explicit MOS, for this TMDL it will be expressed as an implicit MOS because a conservative assumption has been used to determine the value of the TMDL.

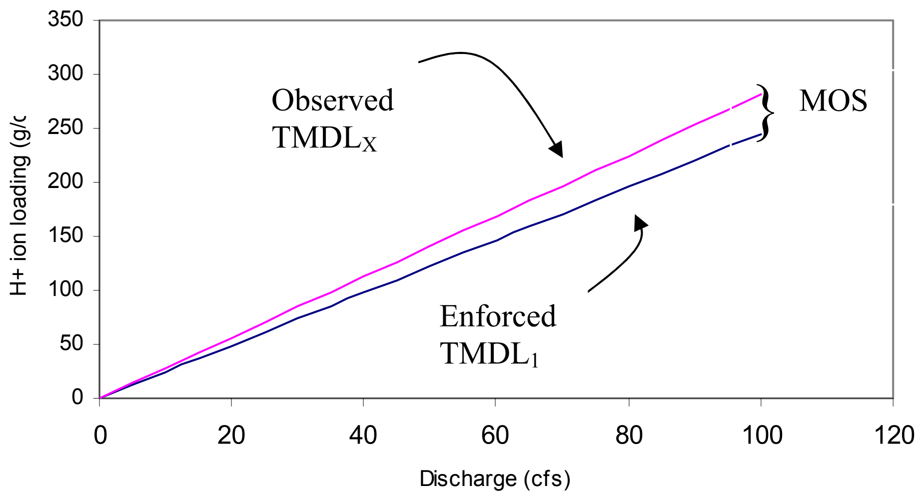


Figure 5. Relation Between Flow (Discharge) and Maximum Ion Loading for a pH of 6.0

Hydrogen Loading Example Calculation

In order to demonstrate the hydrogen loading conversion procedure, use the following data for Site 4 of Wildcat Branch:

- Critical discharge (Q) = 2.3433 cfs (cumulative)
- Measured pH = 6.0

The pH can be converted to a mole/liter measurement (i.e. moles $[H^+]$/liter) by applying the following relationship:

$$pH = -\log \{H^+\}$$

The resulting moles of hydrogen are the anti-log of -6.0, which is 0.000001 moles/liter. The units need to be converted into g/cubic ft. This is accomplished by applying the following conversion factors:

- There is one gram per mole of Hydrogen.
- 1 liter = 0.035314667 cubic feet

$$(0.000001 \text{ moles/liter})*(1 \text{ g/mole})*(1\text{liter}/0.035314667 \text{ ft}^3) = 0.0000283168 \text{ g/ft}^3$$

The goal is to achieve a loading rate in terms of g/day, or lbs/day. If the amount of hydrogen in grams/cubic foot is multiplied by the given flow rate in cubic feet/second and a conversion factor of 86,400 s/day, then the load is computed as:

$$(0.0000283168 \text{ g/ft}^3)*(2.3433 \text{ ft}^3\text{/s})*(86400\text{s}/1\text{day}) = 5.7331 \text{ g/day, or } 0.0126 \text{ lbs/day}$$

Assuming an activity correction factor of 0.87, the maximum load is 6.5898 g/day, or 0.0145 lbs/day:

5.7331 g/day / 0.87 = 6.5898 g/day, or 0.0145 lbs/day

Thus, by using an activity coefficient of 1.0 instead of 0.87 to develop the TMDL values, a MOS of approximately 13 percent is assumed.

Critical Flow and TMDL Determination

Because maximum hydrogen ion loading values can be directly related to flow rate (Figure 5), the associated allowable ion loading exceedance frequency can be directly related to the frequency of the flow. In order to find the lowest 10-year average annual discharge for the Wildcat Branch watershed, a regional hydrologic frequency analysis was used. Regional analysis can be used to develop an inductive model using data collected at streamflow gaging stations that are located in the same hydrologic region as the watershed of interest. For this study, the following US Geological Survey (USGS) gaging stations were selected: 03400500, 03402000, and 03304500. The data from these gages were used to estimate the lowest average annual flows of the most recent 10 years (see Table 2). Because there were no gaging stations that had a contributing drainage area comparable to the subbasins in this watershed under study and for which data was available for the last 10 years, historic data (1950-1960) were used in developing the regional flow-area curve. These flows were then regressed with watershed area to produce Figure 6. Using this figure, the lowest 10 year mean annual flow for a given watershed area can be readily determined.

Table 2. Lowest 10-year Mean Annual Flow Rates (cfs) for Stations in Regional Analysis

	USGS Gaging Station Numbers		
Station	03304500	03402000	03400500
Area (mi^2)	2.14	60.6	82.3
Q (cfs)	1.02	78.9	96.2

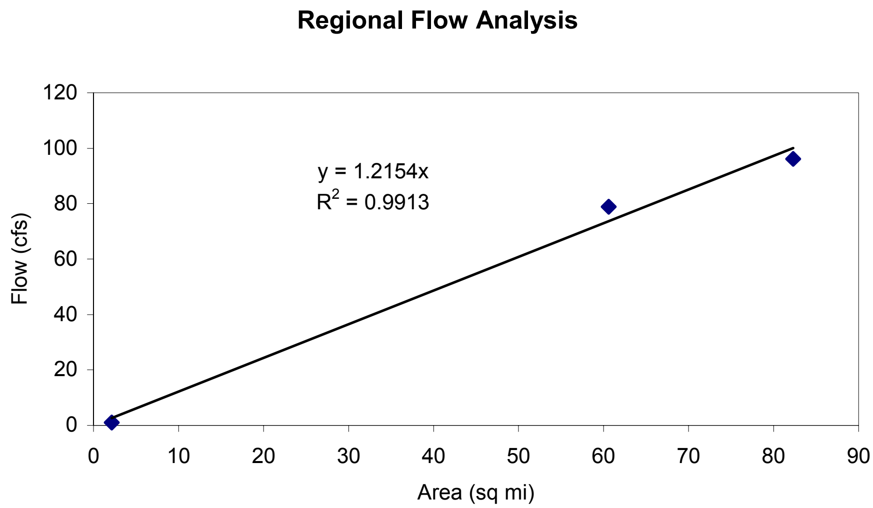


Figure 6. Relation Between Basin Area and the Critical TMDL Flow

Application of Figure 6 for the Wildcat Branch watershed yields a TMDL critical average annual flow for all the subbasins in this watershed for which a TMDL will be developed (for Subbasin 4, the flow calculation is 1.2154 x 1.9280 = 2.3433). Application of these critical flows (the lowest 10-year mean annual flow) with the lower $TMDL_1$ curve in Figure 5 yields a TMDL for Subbasins 1, 2, 3, and 4 (see Hydrogen Loading Example Calculation on page 12). These results are summarized in Table 3. The incremental TMDL is calculated by subtracting the cumulative TMDL for all directly contributing subbasins from the cumulative TMDL for the subbasin of interest. For example, the incremental TMDL for Subbasin 4 is calculated by subtracting the cumulative TMDLs for Subbasins 1, 2, and 3 from that of Subbasin 4 (0.0126 – 0.0018 – 0.0055 – 0.0007 = 0.0046).

Table 3. Lowest 10-year Mean Annual Flows and Corresponding TMDL

Sub-basin	Cumulative Area (mi^2)	Incremental Area (mi^2)	Cumulative Q (cfs)	Incremental Q (cfs)	Cumulative TMDL (lbs/day)	Incremental TMDL (lbs/day)
1	0.2705	0.2705	0.3287	0.3287	0.0018	0.0018
2	0.8456	0.8456	1.0277	1.0277	0.0055	0.0055
3	0.1131	0.1131	0.1375	0.1375	0.0007	0.0007
4	1.9280	0.6988	2.3433	0.8493	0.0126	0.0046

Hydrogen Ion Loading Model

There were no permitted point sources in this watershed during the 2002 monitoring period that contributed to the existing pH impairment. As a result, the current point source load (wasteload) for the Wildcat Branch Watershed is zero. Therefore, the entire hydrogen ion load can be attributed to abandoned mine land (AML) nonpoint sources.

Based on a physical inspection of the watershed, it is hypothesized that the lowering of the pH in the stream is directly related to oxidation of sulfur that occurs as runoff flows over the spoil areas associated with previous mining activities in the basin. Using the most recent monitoring data, inductive models were developed at monitoring sites 1, 2, 3, and 4 that relate total hydrogen ion loading to stream flow. These models are shown in Figures 7-10 and are derived from the data in Table 1. These models were developed by utilizing data points that were within a feasible range of the critical flow for each of the subbasins in the watershed. In developing these models for defining the current load, a conservative value of 0.87 was assumed for the activity coefficient based on the upper limit of measured SC values of 2040 μ ohms/cm.

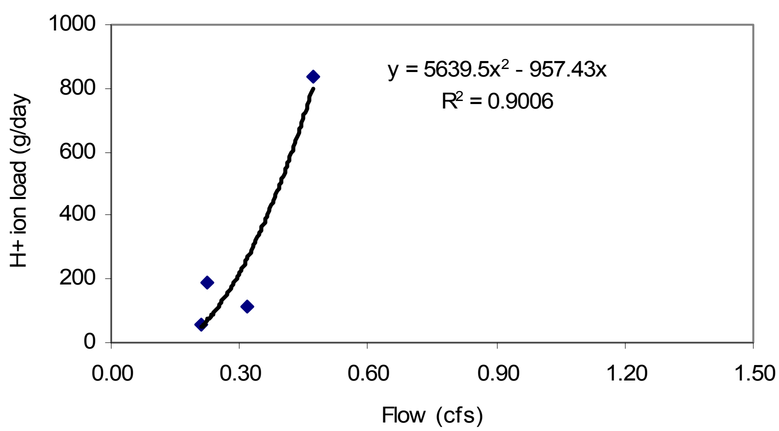


Figure 7. Relation Between Flow and Ion Load for Site 1

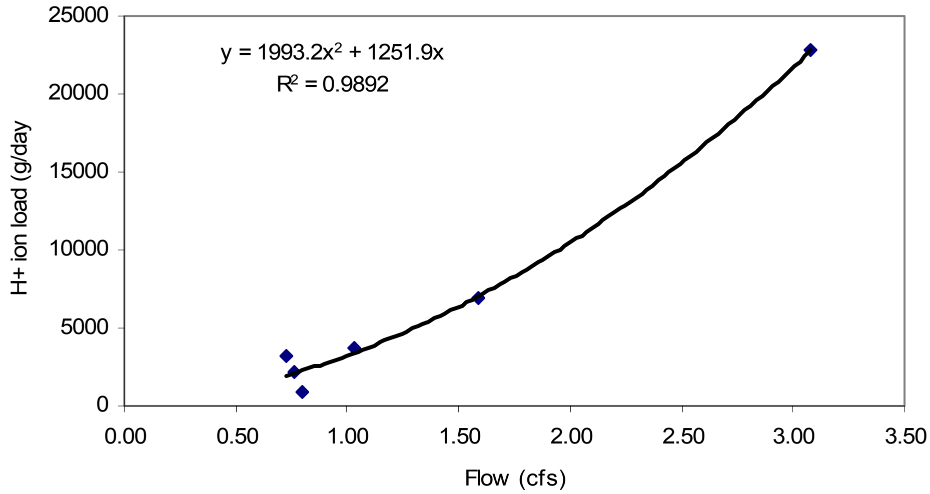


Figure 8. Relation Between Flow and Ion Load for Site 2

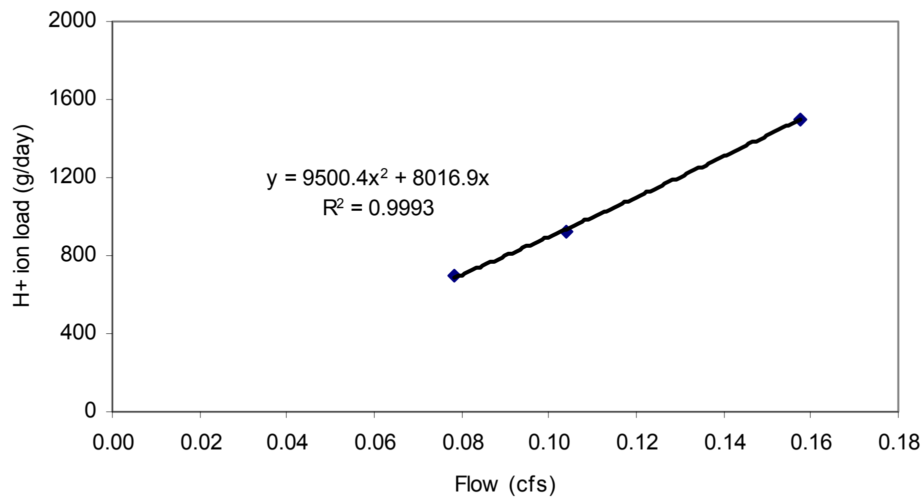


Figure 9. Relation Between Flow and Ion Load for Site 3

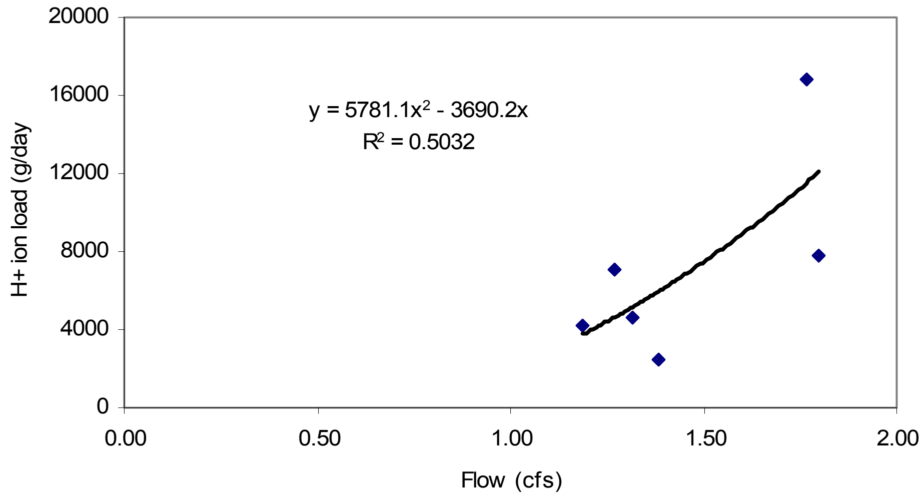


Figure 10. Relation Between Flow and Ion Load for Site 4

The best trend lines through the monitoring data (Figures 7-10) yield the estimated current hydrogen ion loading for different flow values of critical discharge. The trend lines are based on a regression analysis of the observed field data collected at Sites 1, 2, 3, and 4. In each case, the trend lines are developed over the expected flow domain of the critical discharge for each subbasin. Once the trend lines are developed, projected hydrogen ion loadings can be determined for an associated critical discharge. The associated TMDL can then be obtained using the lower TMDL curve in Figure 5. The difference between the critical loading and the TMDL will be the reduction needed for each subbasin.

Predicted Load

The predicted hydrogen ion loads for each subbasin may be obtained using the critical flow from Table 3 and the associated load relation (Figures 7-10). Application of this approach yields the predicted loads for each site as shown in Table 4. An example calculation for Subbasin 4 is $(5781.1) \times (2.3433)^2 - (3690.2) \times (2.3433) = 23{,}097$. Note that for an independent tributary, the incremental load is equal to the cumulative load for that tributary. On the other hand, a subbasin that has flow entering from upstream subbasins requires a mass balance application to find the incremental load. For example, the incremental load for Subbasin 4 is calculated by subtracting the cumulative loads for Subbasins 1, 2, and 3 from the cumulative load of Subbasin 4 (50.9291 – 0.6496 – 7.4787 – 2.8267 = 39.9741). The loading relationship at Site 4 is extrapolated to obtain a loading at the outlet of Subbasin 4.

Table 4. Predicted Cumulative Ion Load for Subbasins 1, 2, 3, and 4

Sub basin	Cumulative Flow (cfs)	Incremental Flow (cfs)	Predicted load (gm/day) Cumulative	Predicted load (lbs/day) Cumulative	Predicted load (lbs/day) Incremental
1	0.3287	0.3287	295	0.6496	0.6496
2	1.0277	1.0277	3,392	7.4787	7.4787
3	0.1375	0.1375	1,282	2.8267	2.8267
4	2.3433	0.8493	23,097	50.9291	39.9741

Load Reduction Allocation

Once a TMDL is developed for a watershed, the needed load reductions can be determined. One way to accomplish this objective is through the use of unit load reductions applied to different land uses within the watershed. The impacts of such reductions in meeting the WQS can then be verified through mathematical simulation. For this TMDL, the hydrogen ion load is entirely associated with AML. Alternatively, separate TMDLs and associated load reductions can be developed for individual subbasins within the watershed. In the current study, separate TMDLs and associated load reductions were developed for each subbasin and a cumulative TMDL and associated load reduction was developed for Subbasin 4 (Figure 3).

Translation of the incremental TMDL in Table 3 into the associated daily load reduction for Sites 1, 2, 3, and 4 may be accomplished by subtracting the incremental TMDL from the incremental predicted loads for these sites (Table 4). For Subbasin 4, the calculation is 39.9741 – 0.0046 = 39.9695. Application of this approach yields the load reduction values in Table 5.

Table 5. TMDL Summary and Reduction Needed for Subbasins 1, 2, 3, and 4

Subbasin	Upstream contributing area (mi^2)	Incremental critical flow (cfs)	Incremental TMDL for a pH of 6.0 (lbs/day)	Predicted incremental load (lbs/day)	Load Reduction needed (lbs/day)
1	0.2705	0.3287	0.0018	0.6496	0.6478
2	0.8456	1.0277	0.0055	7.4787	7.4732
3	0.1131	0.1375	0.0007	2.8267	2.8260
4	0.6988	0.8493	0.0046	39.9741	39.9695
Total Watershed	**1.928**	**2.3433**	**0.0126**	**50.9291**	**50.9165**

Permitting

All of the streams in the watershed are considered to be impaired for low pH based on the available data.

New Permits

New permits (except for new remining permits) for discharges to streams in the Wildcat Branch watershed could be allowed in all subbasins contingent upon end-of-pipe pH limits in the range of 6.35 to 9.0 standard units. WQSs state that the pH value should not be less the 6.0 nor greater than 9.0 for meeting the designated uses of aquatic life and swimming. This range of 6.0 to 9.0 for pH is generally assigned as end-of-pipe effluent limits. However, because a stream impairment exists (low pH), new discharges should not cause or contribute to an existing impairment. Application of agricultural limestone on mine sites results in highly buffered water leaving the site. A buffered solution with nearly equal bicarbonate and carbonic acid components will have a pH of 6.35 (Carew, personal communication, 2004). Discharge of this buffered solution will use up free hydrogen ions in the receiving stream, thus it should not cause or contribute to an existing low-pH impairment. New permits having an effluent limit pH of 6.35 to 9.0 will not be assigned a hydrogen ion load as part of a WLA. There are no active permits in the Wildcat Branch Watershed that would contribute to the existing pH impairment.

Remining Permits

Remining permits may be approved on a case-by-case basis where streams are impaired because of low pH from abandoned mines. Existing water quality conditions must be maintained or improved during the course of mining. Permit approval is contingent on reclamation of the site after mining activities are completed. Reclamation of the site is the ultimate goal, but WQSs (pH of 6.0 to 9.0 standard units) may not necessarily be met in the interim if the Commonwealth issues a variance to the permittee. In instances where the Commonwealth issues a variance for a remining activity consistent with this regulation, hydrogen ion loads from this remining activity are allowed to exceed the WLA. The variance allows an exception to the applicable WQS as well as to the TMDL. Remining therefore constitutes a means whereby a previously disturbed and unreclaimed area can be reclaimed. The authority for remining is defined in Section 301(p) of the Federal Clean Water Act; Chapter 33, Section 1331(p) of the U.S. Code – Annotated (the Rahall Amendment to the Federal Clean Water Act); and the Kentucky Administrative Regulations (401 KAR 5:040 and 5:029).

The eventual reclamation of the remining site should result in a reduction of the nonpoint source ion load of the subbasin. The reclamation should also result in an improved stream condition (increased pH) because a previously disturbed and unreclaimed area will be reclaimed. Follow-up, in-stream monitoring would need to be done at the subbasin outfall to determine the effect of reclamation activities following remining on the overall ion load coming from the subbasin.

General KPDES Permit for Coal Mine Discharges

This permit covers all new and existing discharges associated with coal mine runoff. This permit does not authorize discharges that (1) are subject to an existing individual KPDES permit or application, (2) are subject to a promulgated storm water effluent guidelines or standard, (3) the Director has determined to be or may reasonably be expected to be contributed to a violation of a water of a WQS or to the impairment of a 303(d) listed water, or (4) are into a surface water that has been classified as an Exceptional or Outstanding or National Resource Water. A signed copy of a Notice of Intent (NOI) form must be submitted to the Kentucky Division of Water (KPDES Branch) when the initial application is filed with the Division of Mine Permits. However, coverage under this general permit may be denied and submittal of an application for an individual KPDES permit may be required based on a review of the NOI and/or other information.

Antidegradation Policy

Kentucky's Antidegradation Policy was approved by EPA on April 12, 2005. For impaired waters, general permit coverage will not be allowed for one or more of the pollutants commonly associated with coal mining (i.e., sedimentation, solids, pH, metals, alkalinity of acidity). The individual permit process remains the same except new conditions may apply if a Total Maximum Daily Load (TMDL) has been developed and approved.

Distribution of Load

Because there were no point source discharges in the watershed that contributed to the existing low pH impairment during the monitoring period, the entire load was defined as nonpoint source load. Because new permits (pH 6.35 to 9.0) and remining permits would be exempt from the TMDL requirements, no load has been provided for the WLA category (Table 6).

Table 6. Wasteload and Load Allocation for Each Subbasin

	Incremental Critical Flow Rate (cfs)	TMDL for pH = 6.0 (lbs/day)	Wasteload Allocation* (lbs/day)	Load Allocation (lbs/day)
Subbasin 1	0.3287	0.0018	0.00	0.0018
Subbasin 2	1.0277	0.0055	0.00	0.0055
Subbasin 3	0.1375	0.0007	0.00	0.0007
Subbasin 4	0.8493	0.0046	0.00	0.0046

*pH limits for new discharges must be between 6.35 and 9.0

Implementation/Remediation Strategy

Remediation of pH-impaired streams as a result of current mining operations is the responsibility of the mine operator. The Kentucky Division of Field Services of the Department of Surface Mining Reclamation and Enforcement is responsible for enforcing the Surface Mining Control and Reclamation Act of 1977 (SMCRA). The Kentucky DAML is charged with performing reclamation to address the impacts from pre-law and bond forfeiture mine sites in accordance with priorities established in SMCRA. SMCRA sets environmental problems as third in priority in the list of AML problem types.

Practical application of pH TMDLs, especially for abandoned mine lands, will normally involve a phased implementation approach with associated monitoring in order to insure that the implemented measures are having the desired effect. Typical remediation strategies have involved channel restoration, re-vegetation, and the use of agricultural limestone. On sites where applicable, and funding allows, passive treatment systems have been used to treat AMD including open limestone channels, vertical flow systems, limestone dosing, and constructed wetlands.

As discussed earlier, three separate remediation projects have been implemented in the Wildcat Branch watershed. It is expected that these projects should lead to continuing improvements of the water quality in the watershed.

Reclamation activities are underway at other locations within the state where water quality is affected by AMD. Examples of reclamation projects addressing AMD in the Upper Cumberland River watershed are summarized in Table 7.

Table 7. Reclamation Projects Addressing AMD in the Upper Cumberland

Watershed	Project Name	Cost
Back Creek	Pruden-Fonde Reclamation Project	$840,000
Rock Creek	Rock Creek AMD Abatement Projects	$1,300,000

For 2000, the total federal Kentucky AML budget allocation was approximately $17 million. However, the bulk of these funds were used to support Priority 1 (extreme danger of adverse effects to public health, safety, welfare, and property) and Priority 2 (adverse effects to public health, safety, and welfare) projects. Of the total annual federal budget allocation, AML receives only approximately $700,000 in Appalachian Clean Streams Initiative funds, which are targeted for Priority 3 environmental problems. Based on the cost of current remediation efforts, it would appear that a significant increase in federal funding to DAML projects, particularly Priority 3 projects, would be required in order for the DAML program to play a significant part in meeting the TMDL implementation associated with pH-impaired streams in the state of Kentucky.

Load Reduction Strategy Using Limestone Sand

Recent studies in Kentucky (Carew, 1998) and West Virginia (Clayton, et. al., 1998) have demonstrated that limestone sand can be used as an effective agent for restoring the pH in acidified streams. For streams with a pH < 6, $CaCO_3$ may be used to neutralize free hydrogen ions based on the following relationship:

$$CaCO_3 + 2H^+ \rightarrow H_2CO_3 + Ca^{2+} \qquad (11)$$

Thus, the theoretical total mass of $CaCO_3$ required to neutralize 1 gm of H^+ ions can be obtained by dividing the molecular weight of $CaCO_3$ (100) by the molecular weight of 2 hydrogen atoms (2) to yield:

$$\text{Required mass of limestone} = 50^*\text{Mass of Hydrogen Ions} \qquad (12)$$

Or, in terms of a required annual load:

$$\text{Annual required mass of limestone} = 18{,}250^*\text{Mass of Hydrogen Ions (g/day)} \qquad (13)$$

In practice, however, this value will only represent a lower bound of the required mass as a result of two issues: 1) not all the limestone added to a stream will be readily available as soluble $CaCO_3$, and 2) an increasing fraction of the $CaCO_3$ mass will be required to neutralize other metal ions (e.g. Fe, Al, Mn) that will also most likely be present in the acid mine drainage, especially in the case of streams with pH < 4.5 (Snoeyink and Jenkins, 1980).

One way to deal with the first limitation is to simply add more limestone to the stream. Recent studies in both West Virginia and Kentucky have found that application rates of 2 to 4 times the theoretical limestone requirement have been found to be effective in restoring AMD streams. The most effective way to deal with the second limitation is to determine the additional amount of limestone that must be added to neutralize both the hydrogen ions and the additional ions that might be present. One way to approximate this quantity is by calculating the total acidity in the water column (as expressed directly as $CaCO_3$).

Total acidity is normally defined as a measure of the concentration of acids (both weak and strong) that react with a strong base. Acidity may be determined analytically by titrating a water sample with a standard solution of a strong base (e.g. NaOH) to an electrometrically observed end point pH of 8.3. (For waters associated with acid mine drainage it is important that any ferric salts present must first be oxidized prior to the determination of the total acidity). The required mass of NaOH required to raise the sample pH to 8.3 can then be expressed directly in terms of $CaCO_3$ as follows:

$$\text{Acidity, as mg } CaCO_3 = \frac{50{,}000^*(\text{mL of NaOH})^*(\text{Normality of NaOH})}{\text{Weight of sample used (mg)}} \qquad (14)$$

In general, a relationship between pH (or the associated mass of free hydrogen ions), and the total acidity can be readily developed for a given stream using measured values of pH and acidity (Clayton, et. al, 1998). Using measured streamflow data, an additional relationship between the required hydrogen ion reduction (required to raise the pH up to 8.3) and the corresponding load of $CaCO_3$ (required to neutralize both the hydrogen ions and other free ions) can also be developed, as shown in Figure 11. In this particular case, Figure 11 was constructed from an analysis of data from five separate watersheds in the eastern Kentucky Coal Fields, and thus provides a regional curve for application to similar watersheds in the area. A similar curve could be developed for application to watersheds in other areas using regional data for that area. Alternatively, a site-specific curve could be developed for an individual watershed using measured values of flow, pH, SC, and total acidity.

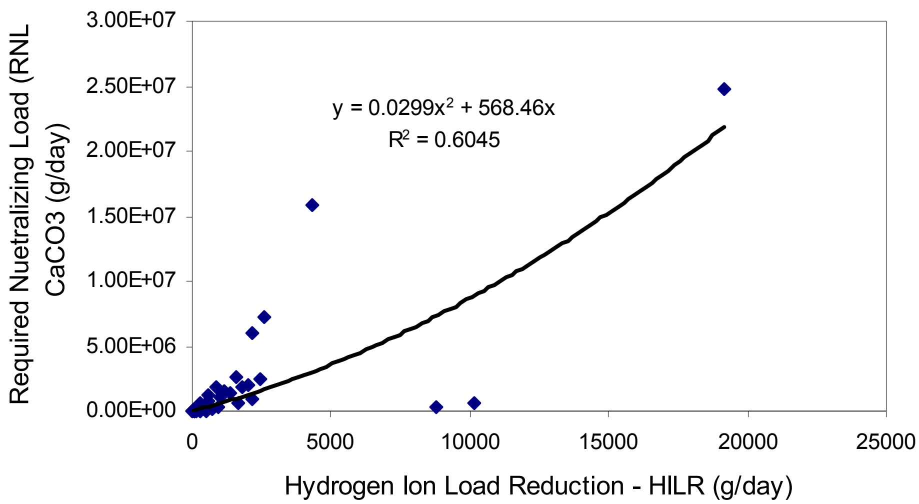


Figure 11. Relation Between $CaCO_3$ Loading and the Required Hydrogen Ion Reduction

For the case of Wildcat Branch, site-specific stream acidity data were not collected as part of the overall sampling effort. As a result, the required $CaCO_3$ loading was determined using the regional curve. It should be recognized that the loading values produced by application of Figure 11 should theoretically increase the pH to 8.3 (based on the definition of total acidity), although pragmatically the achieved value will likely be less. As a result, Figure 11 is likely to provide a conservative estimate of the $CaCO_3$ loading required initially for a particular stream. Subsequent applications of additional limestone can be further refined through follow-up monitoring.

Application of Figure 11 using the required hydrogen ion load reduction values shown in Table 5 yields the corresponding values of $CaCO_3$ loadings shown in Table 8 [for Subbasin 4, the calculation is: $(0.0299) \times (18{,}127)^2 + (568.46) \times (18{,}127)= 20{,}129{,}259$]. A corresponding approximation of the annual loading required can be obtained by simply multiplying the daily values by 365. Based on the work of Clayton, et. al., (1998), it is recommended that the values in Table 8 be multiplied by a factor of 2 to 4 in order to provide a conservative estimate of the initial loading.

Table 8. $CaCO_3$ Loadings for Wildcat Branch

	Required reduction (lbs/day)	Required reduction (g/day)	$CaCO_3$ loading (g/day)	$CaCO_3$ loading (lbs/day)	$CaCO_3$ loading (tons/yr)
Subbasin 1	0.6478	294	169,712	374	68
Subbasin 2	7.4732	3,390	2,270,693	5,007	914
Subbasin 3	2.8260	1,282	777,907	1,716	313
Subbasin 4	39.9695	18,127	20,129,259	44,377	8,100

Public Participation

This TMDL was placed on 30-day public notice and made available for review and comment from Nov. 15 through Dec. 15, 2005. The public notice was prepared and published as an advertisement in the Commonwealth Journal, a newspaper with wide circulation in Pulaski County. A press release was also distributed to newspapers statewide. In addition, the press release was submitted to approximately 275 persons via a Kentucky Nonpoint Source electronic mailing distribution list.

The TMDL was made available on KDOWs website at www.water.ky.gov/sw/tmdl, and hard copies could be requested by contacting the KDOW. The public was given the opportunity to review the TMDL and submit comments to KDOW in writing prior to the close of the public comment period. At the end of the public comment period, all written comments received became part of KDOWs administrative record. KDOW considered all comments received by the public prior to finalization of this TMDL and subsequent submission to EPA Region 4 for final review and approval.

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APPENDIX A: MINING PERMITS NUMBERING SYSTEM

XXXX-XX Permit issued prior to May 3, 1978. Ex. 1357-76. The first four numbers represent the mine number. The last two numbers represent the year of issuance.

XXX-XXXX Permit issues after May 3, 1978. The first three numbers indicate the location of the mine by county and the timing of the original permit issuance. (Ex. Hopkins County = 54).

If the first three numbers correspond to the county number, the permit was originally issued during the interim program.

If 200 have been added to the county number, the permit was originally issued prior to May 3, 1978, and carried through into the interim program. Ex. 254 (Hopkins)

If 400 has been added to the county number the permit was issued prior to the Permanent Program and was to remain active after January 18, 1983. Ex. 454 or 654 (Hopkins)

If 800 has been added to the county number: (1) the application is for a permit after January 18, 1983 or (2) two or more previously permitted areas have been combined into a single permit. Ex. 854 (Hopkins)

The last four numbers indicate the type of mining activity being permitted.

COAL

0000-4999	Surface Mining
5000-5999	Underground Mine
6000-6999	Crush/Load Facility
7000-7999	Haul Road Only
8000-8999	Preparation Plant
9000-9399	Refuse Disposal

NON-COAL

9400-9499	Limestone
9500-9599	Clay
9600-9699	Sand/Gravel
9700-9799	Oil Shale
9800-9899	Flourspar